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What is The Impact of China's Entry into the WTO on CO2 Emissions?

By Yuqi Duan*

Abstract

This study investigates the impact of China's entry into the WTO on carbon dioxide emissions from a global standpoint. A panel of production-based CO2 emissions and consumption-based CO2 emissions of 39 countries from 1995 to 2007 is constructed by integrating country-sector level data from WIOD. Using a triple difference design, I observe additions in production and consumption emissions after this specific trade openness event. The results vary according to the country's income level. For example, this event has a more significant effect in developed countries than developing countries. The above results are due to the growth in both production and consumption emission intensities after the event. Notably, the magnitude of the increase in the production emissions is smaller than the consumption emissions, thus inferring that the CO2 emissions embodied in domestic production used for exports or final consumption partially decrease through the growing high-emission intensity intermediate goods imported from China.

JEL Codes: F18, Q53, Q54

Keywords: trade liberalization, China' entry into the WTO, production CO2 emissions, consumption CO2 emissions, developed and developing countries

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1 Introduction

In past decades, the topic of climate change as a result of global warming has become a prominent concern in the international community, considering its detrimental consequences on the sustainable development of humankind and ecosystems. According to Olivier & Peters (2019), carbon dioxide (CO2), as the major component of greenhouse gases, is the primary driver of global warming. The United States Environmental Protection Agency (EPA) perceive that the volume of CO2 emissions has proliferated by 90% during 1995-2007 (EPA, 2021). Consequently, understanding the factors related to CO2 emissions has become a prevalent topic in the academic world (Sharma, 2011; Ren et al., 2013; Cosmas et al., 2019; Mujtaba et al., 2020). With the accelerating pace of globalisation, international trade also has experienced a rapid increase for decades. World Development Indicators (WDI) has found that the total amount of international trade has risen by 726% from 1970 to 2011 (WDI, 2021a). The contemporaneous sharp growth in CO2 emissions and international trade in the recent decades has piqued researchers' interest, promoting plentiful scholars to explore the relationship between them (Shahbaz et al., 2013; Gu et al.,2013; Ren et al., 2013; Xu & Dietzenbacher, 2014; Mutascu, 2018; Levitt et al., 2019; Essandoh et al., 2020; Hu et al., 2020; Dauda et al., 2021).

In December 2001, China joined the World Trade Organization (WTO), and this specific event had far-reaching impacts on both China's and the world's trade openness as China's average tariff diminished from 14.1% to 5.99% during the succeeding ten years (WDI, 2021b). The accession of China to the WTO gives an excellent chance to investigate the consequences of a trade liberalisation event on CO2 emissions since it is the world's largest developing country exporter (Bloom et al., 2016) and the world's largest CO2 gas emitter (ESSD, 2020). Numerous recent papers have looked at this event's influence on economic growth (Sache & WOO, 2003; Ghosh & Rao, 2010; Urdinez & Masiero, 2015), on innovation (Cheung & Lin, 2004 and Bloom et al., 2016), and on the labour market (Zhu & Warner, 2004; Kwan, 2009; Dai et al., 2020), whereas the empirical evidence about its on CO2 emissions is not only limited but also controversial. Therefore, this paper intends to fill the gap in existing literature focusing on the impact of China's admission to the WTO on global CO2 emissions. This dissertation aims to answer the following questions: (1) What is the impact of a liberalising trade event in China on production-based and consumption-based CO2 emissions? (2) Is this impact varying with a country's income level? (3) What is the change of CO2 emissions embodied in the trade induced by this event? (4) What are the potential channels through which this event has effects on emissions?

The paper uses data from the input-output table, the environmental satellite account and the socio-economic account in World Input-Output Database (WIOD). The benefit of the data in the WIOD lies in tracking all the flows of CO2 emissions throughout the global production chains and discovering the emissions embodied in the international trade. This study adopts a triple-difference (DDD) design to assess the relationship between China's accession to the WTO and CO2 emissions. I construct a panel dataset for CO2 emissions from 1995 to 2007, covering 35 sectors across 39 countries. To fully comprehend the effects of China's inclusion in the WTO, I compute two types of CO2 emissions — the production-based emissions emitted from domestic production of goods regardless of the place they are consumed (export or domestic), and the consumption-based emissions emitted from the production of goods used for domestic consumption regardless of the place they are produced (import or domestic). The difference between these two measures could shed light on the potential emissions from international trade. Both production and consumption emissions are constructed by adopting a multi-regional IO model.

This research finds that China's joining the WTO significantly impacts its trading partners' CO2 emissions using the above data. For sectors with high exposure to Chinese trade, this event tends to raise production-based and consumption-based emissions. The effects on emissions are contingent on the country's income level. Specifically, the effects tend to drop for the former when contrasting between developing and developed countries. The above outcomes originate from the increase in both production and consumption emission intensities. Remarkably, the addition in production emissions is lower than consumption emissions. The divergence between production and consumption emissions could be interpreted by the partial reduction in the emissions embodied in products that are produced domestically used for exports or final domestic consumption compared to the emissions embodied in import trade. As a result, consumption CO2 emissions increase more after this event by considering the composition and scale effects. The outcomes are consistent across a variety of validity checks.

This paper contributes to the existing literature by the following three aspects. First, to my knowledge, this is the first study to assess the association between China's entry into the WTO on global CO2 emissions across all sectors and countries by employing a DDD model. Second, this paper differentiates the effect of this trade openness event on emissions by the country's income level. It fills the knowledge gap since current studies remain unclear when considering the influence of Chinese trade on emissions in countries of different income levels. Finally, this study comprehensively quantifies the CO2 emissions transfer embodies in international trade originating from this event by providing production and consumption emissions across sectors and countries from 1995 to 2007.

The rest of this paper is organised as follows. Section 2 provides an overview of the literature. Section 3 displays the empirical strategy, which includes model specifications and identification method. The dataset utilised for estimations and the construction of the main variables are briefly discussed in Section 4. The portrayal of the results is reported in Section 5, followed by the corresponding discussions of results and potential mechanisms. Section 6 presents approaches used to verify the validity and several robustness checks. Finally, Section 7 concludes.

2 Literature Review

2.1 China’s Trade Openness and CO2 emissions

With the soar in both the amounts of China’s international trade and CO2 emissions since 1970, several studies have started to focus on the impact of Chinese trade on CO2 emissions within China and on a global scale. Some studies have shown that trade has increased global CO2 emissions (Gu et al.,2013; Ren et al., 2013; Xu & Dietzenbacher, 2014; Jun et al., 2020), while some other studies have found a negative relationship between trade openness and global CO2 emissions as it promotes carbon emissions reduction (Vennemo et al., 2008 and Chen et al., 2019). For example, using time series data from 1981 to 2010, Gu et al. (2013) suggest a long-term equilibrium relationship between CO2 emissions and trade openness in China. Meanwhile, Ren et al. (2014) find that the rapid expansion in CO2 emissions in China is caused by the growing international trade. Xu & Dietzenbacher’s (2014) show that the total volume of carbon emissions related to exports from China to the world market has accelerated by 207% between 1970 and 2011, further reinforcing this association. However, Chen et al. (2019) argue that foreign trade lessens CO2 emissions in China by observing an Environmental Kuznets Curve (EKC) of emissions.

Scholars have also turned the spotlight on investigating the influence of a specific event — China’s participation in the WTO on emissions. Jun et al. (2020) suggest that the rising trade contributes to the sharp expansion of air pollution in China, especially after China accedes into the WTO. In contrast, Vennemo et al. (2008) discover that CO2 emissions in China decreased after this liberalising trade event by taking the composition effects into account. Thus, existing works of literature have shown inconclusive evidence about the impact of China’s trade on CO2 emissions.

2.2 Trade Openness, CO2 Emissions, and Income Level

Trade openness is beneficial to promote economic growth across different countries since it leads to an augment in income (Sikder et al., 2019). An expansion in energy consumption and enhancing production activities usually accompany this process, and this enhancement tendency thereby influences the environment (Shahbaz et al., 2017 and Forslid et al., 2018). Empirically, some studies have explored trade’s effect on CO2 emissions in various countries and have drawn different conclusions. From the opinion of developing countries, trade openness often leads to CO2 emissions. Ozturk & Acaravci (2013) prove the EKC hypothesis in Turkey’s economy, which means that an expansion in Turkish trade would increase carbon emissions in Turkey. However, from developed countries, many scholars believe that trade openness would be conducive to reducing CO2 emissions. Forming from Swedish enterprise-level data, Forslid et al. (2018) evaluate the impact of export trade on CO2 emissions in Sweden and find that overall, export trade facilitates CO2 emissions reduction. Additionally, some studies concentrate on a global context to explore the relationship between trade liberalisation and CO2 emissions. Stretesky & Lynch (2009) observe the positive impact of exports to the United States (US) on global CO2 emissions by collecting panel data for 169 countries.

From the studies mentioned above, I observe that the specific impact of trade openness on CO2 emissions is contingent on the country's income level (Kellenberg, 2008; Managi et al., 2009; Baek et al., 2009; Perkins & Neumayer, 2012; Kim et al., 2019). Previously, Kellenberg (2008) point out the effect of income heterogenous and reveal that trade liberalisation is detrimental to the environment for middle-income and low-income countries, while for high-income countries, trade liberalisation has a beneficial impact. Similarly, Managi et al. (2009) further reinforce this effect and suggest that trade decreases CO2 emissions in OCED countries, whereas in non-OCED countries, it creates adverse influences. However, according to Baek et al. (2009), China follows an opposite pattern, in which trade contributes to CO2 emissions reduction for developing countries and has opposite effects for developed countries. The above studies try to disclose the association between trade openness, CO2 emissions and income level from an integral scope of trade to evaluate the association, failing to reveal this relationship from the scope of investigating the sectoral structural differences. Furthermore, the current studies have mixed and ambiguous conclusions about the association between China's trade openness, CO2 emissions and income level. Therefore, it is essential to implement a broader range of research to obtain comprehensive and universal conclusions.

2.3 Input-output (IO) Analysis and Carbon Emissions Embodied in Trade

In current literature, CO2 emissions embodied in trade are mainly generated by IO analysis using the world input-output tables (WIOT). Using a multi-regional IO model, Guo et al. (2012) yield the provincial CO2 emissions containing 28 sectors in 30 provinces of China. The results indicate that CO2 emissions embodied in China's trade are mainly from eastern China and are mainly contributed by energy-intensive and labour-intensive sectors. In Dong et al.'s (2010) study, they find that the prime driving force of rising CO2 emissions between China and Japan is from their expanding bilateral trade from 1990 to 2000 by analysing China-Japan IO data and using the index decomposition analysis method. However, the existing studies mainly centre on a region or a country when they employ IO analysis, failing to provide the empirical evidence of the transfer of CO_2 emissions in a global perspective originated by one country's trade liberalisation event.

2.4 Summary

In summary, this paper makes several contributions to current literature. First, to the best of my knowledge, few studies estimate the potential effects of China's entry into the WTO on CO_2 emissions from a global scale using econometrics methods. Given the insufficient evidence of this specific event, this research complements the literature gap under a DDD framework. Second, by distinguishing variations between developed countries and developing countries, this paper takes income levels into account and verifies whether the impact of trade openness on CO_2 emissions depends on countries' income levels. Last, this paper combines IO analysis with the econometric model to quantify the CO_2 emissions transfer embodied in international trade caused by one country's trade opening event.

3 Methodology

According to Bertrand et al. (2004), it is prevalent to adopt a difference-in-difference (DID) estimation to evaluate casual relationships, especially when researchers measure the effect of a particular intervention such as an implementation of policy and enactment of a law. The basic DID estimates the influence of a specific treatment by comparing the alternations in outcomes over time between the intervention group and control group, which mitigates the effects from endogeneity problems and selection bias that typically happen when comparing heterogeneous observations (Angrist & Pischke, 2008). Additionally, to differentiate the potential disparate responses between developed and developing countries, this study will add another interaction term and employ a DDD framework as the primary model to estimate the influence of China's accession into the WTO on the world CO2 emissions.

3.1 Model Specification

The identification strategy in this paper exploits the exogenous change through China's entry into the WTO, a straightforward indicator variable WTO_t is established first to represent this event's time point. 2002 is chosen as the beginning year of post-WTO periods because this event only partially affected the trade exposure for below one month in 2001.[1] Another dummy variable $TREAT_{i,s}$ shows the status of treatment and control groups, and it equals to one if sectors are in the high exposure group. The fundamental regression is as follows:

$$CO2^{j}_{i,s,t} = \beta_0 + \beta_1 WTO_t + \beta_2 TREAT_{i,s} + \beta_3 (TREAT_{i,s} \times WTO_t) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$$

$$WTO_t \begin{cases} = 1, \text{after China's accession into WTO} \\ = 0, \text{before China's accession into WTO} \end{cases}$$

$$TREAT_{i,s} \begin{cases} = 1, \text{treatment group} \\ = 0, \text{control group} \end{cases}$$

In the above specification, $CO2^{j}_{i,s,t}$ represents the production CO2 emissions $CO2^{P}_{i,s,t}$ or the consumption CO2 emissions $CO2^{C}_{i,s,t}$ for i country in s sector in t year. This regression includes crucial effects for sectors $TREAT_{i,s}$ and year WTO_t and an interaction term $TREAT_{i,s} \times WTO_t$, which

[1] Post-WTO years include 2002-2007 though China has been a member of the WTO since December 11, 2001. Pre-WTO years include 1995-2001.

capture observations from the treatment group after China accedes to the WTO. β_0 represents the average CO2 emissions alternation of the control group before China enters into the WTO. β_1 reveals the average CO2 emissions change for the control group after China enters the WTO. β_2 stands for the discrepancy in CO2 emissions between the treated and control group before China participates in the WTO. β_3 is the coefficient of interest, which reports the average treatment effect on the treatment group compared to the 'common' trend shaped by the control group. $Z_{i,s,t}$ incorporate a set of control variables that contain total labour hours, low-skilled labour hour share, real gross output, and gross fixed capital share, which alleviate potential selection bias, and $u_{i,s,t}$ are the unobserved factors. Compared to a cross-sectional regression that evaluates the divergence between treatment and control groups and a time series regression that evaluates change over time, this simple regression setup excludes extraneous factors except for the treatment by removing the 'parallel' outcome.

After constructing a fundamental model, finding an appropriate counterfactual to observe the common trend in the absence of the treatment is essential in this paper. Since it is hard to measure the effect on China's trade exposure with other countries across multiple sectors, identifying reasonable treatment and control groups are challengeable. However, by utilising the change in import exposure across different domestic sectors before China participated in the WTO[2], this paper could establish a method to identify the causal treatment effect. The heterogeneity exists in the domestic sectors' growth prior to China entering the WTO, which indicates that the comparative advantage across domestic sectors is various. After its admission to the WTO, sectors are exposed to different growth rates, implying that the sectors with more comparative advantages could attain higher increasing rates in imports and vice versa. Thus, the difference in import exposure across domestic sectors prior to China's entry into the WTO provides a unique strategy to divide the treatment and the control group. The year 2000 as one year before joining the WTO[3], is chosen as the benchmark year since China's exports across these sectors are already strong in that period and have experienced a considerable rise in imports following the accession into the WTO. In regard to Amiti & Freund (2010), the aggregate expansion of China's imports comes from growth in existing products instead of growth in new products for at least three quarters from 1997 to 2005. The sectors that have high exposure in import before 2000 are in the treatment group, and the sectors that have low exposure in import before 2000 are in the control group.

[2] Bloom et al. (2016) also employ a similar identification method.

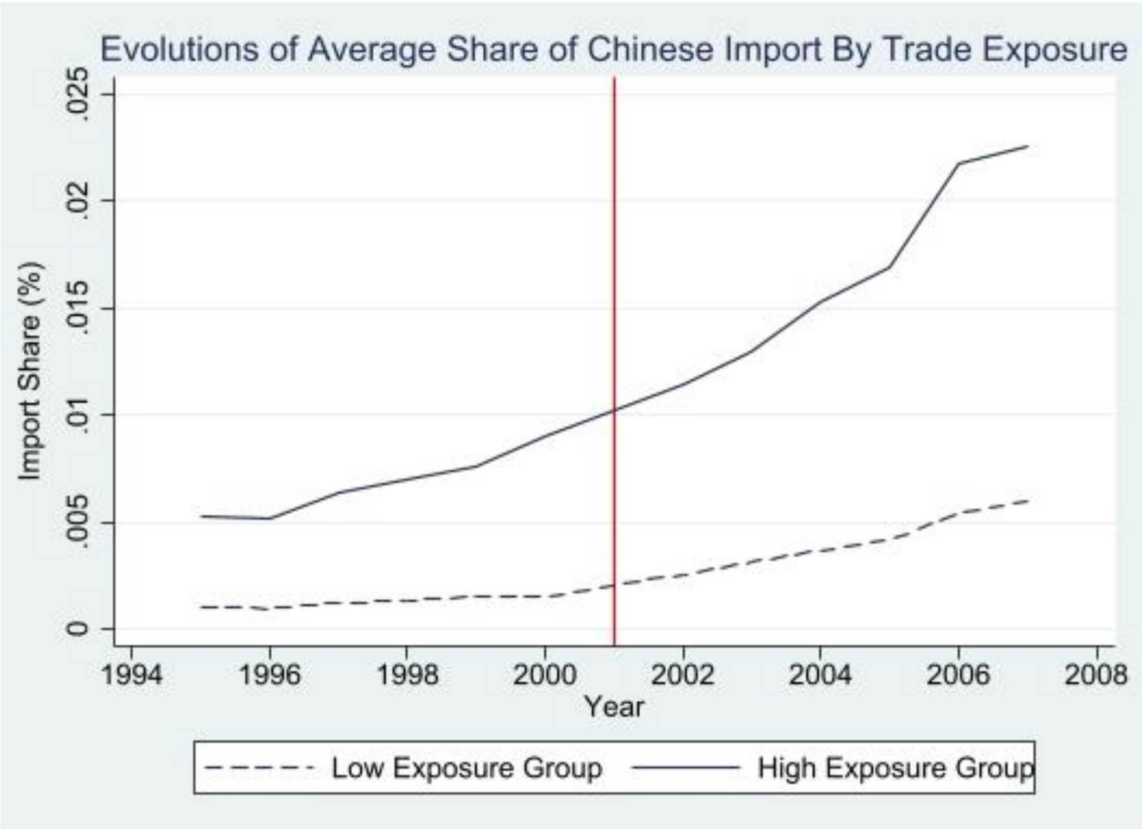
[3] Since China entered the WTO in December 2001, I choose 2000 to generate my treatment and control groups.

By applying Bernard et al.'s (2006) import share method, this paper measures import trade exposure to China using the Chinese trade share of aggregate imports. The import share $IS_{i,s,2000}^{China}$ is calculated to measure the degree of trade exposure at the country-sector level using the following equation:

$$IS_{i,s,2000}^{China} = \frac{\mathrm{ES}_{i,s,2000}^{China}}{\mathrm{ES}_{i,s,2000}^{World}}$$

Where i indexes each country, s indexes each sector and 2000 indexes year 2000. The trade exposure is evaluated by $\mathrm{ES}_{i,s,2000}^{China}$, which represents the value of Chinese imports to country i's sector s in 2000, as a share of $\mathrm{ES}_{i,s,2000}^{World}$, which represents aggregate world imports for sector s in country i in 2000.[4]

Figure 1: Evolutions of Average Share of Chinese Import by Trade Exposure[5]



Based on the above approach, I use the data from the WIOT in the year 2000 to generate Chinese import shares for 35 sectors in 39 countries (exclude China) and use the median as the benchmark observation. The sectors above the median import share in 2000 are categorised as high exposure

[4] Note that aggregate world imports refer to the total amount of imports of China plus the other 39 countries in WIOT.

[5] Source: WIOT.

sectors and divided into the treatment group. For the remaining observations, they constitute the control group, which belongs to low exposure sectors. By decomposing sectors into high exposure and low exposure groups, Figure 1 graphs the average share of China's imports for each group over 1995 to 2007, further validating the variations in trade exposure across sectors before China participates in the WTO. Following the six years in the post-WTO period from 2002 to 2007, the average share of China's import sharply expands for high exposure sectors, whereas the average share has a flatter trend for low exposure sectors. Moreover, the average shares for both high exposure and low exposure sectors are not significantly different prior to the inclusion in the WTO.

Though the above DID framework is conducive to estimating the causal effect at the aggregate level, potential disadvantages may arise in this simple regression. Firstly, it ignores the disparate effects of the treatment on observations as they come from various countries and sectors. For instance, Baek et al. (2009) and Managi et al. (2009) demonstrate that the impacts of trade on CO2 emissions vary with income level among countries. Additionally, there exist deviations depending on sectors' import dependencies and intrinsic attributes, resulting in varying degrees of response across sectors to the event of China's inclusion into the WTO in CO2 emissions. Secondly, this regression only concentrates on one period before and after this event, failing to trace the subsequent effects over time. For example, trade tends to become closer links between countries and across sectors after entering the WTO and could have a more influential impact on emissions over time.

Based on the above basic DID model, this paper follows a more comprehensive DID setup with multiple time periods developed by Gruber (1994), which contains a unified indicator variable covering periods and groups subject to the event. Firstly, it adds the fixed effects at the country-sector level to control for the varying degrees of response across countries and sectors in the face of the treatment. Furthermore, this model includes year effects to control the time trend of potential factors as they may change over time. Aside from examining many phases in both pre-WTO and post-WTO periods, this regression further comprises fixed effect and year effect, and it is expressed in the following estimation equation:

$$CO2_{i,s,t}^{j} = \alpha_{i,s} + \gamma_t + \lambda_1 (TREAT_{i,s} \times WTO_t) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$$

Where i indexes each country, s indexes each sector and t indexes year. $\alpha_{i,s}$ is the group fixed effect at the country-sector level and γ_t is the time fixed effect. λ_1 is the coefficient of interest.

As I mentioned in the literature review, the effect of trade openness on CO2 emissions may depend on the country's income level to a certain extent (Kellenberg, 2008; Managi et al., 2009; Baek et al.;

Perkins & Neumayer, 2012; Kim et al., 2019). Hence, a triple-difference method in line with the research of Imbens & Wooldridge (2007) and Duggan et al. (2016) will be employed to measure the distinction between developed and developing countries, which is considered as the core analysis of this research. I encompass an additional dummy variable DI_i, which equals one if the country i is categorised as a developing country[6], and the main model is as follows:

Equation 1: $CO2^{j}_{i,s,t} = \alpha_{i,s} + \gamma_t + \lambda_1\left(TREAT_{i,s} \times WTO_t\right) + \lambda_2\left(TREAT_{i,s} \times WTO_t \times DI_i\right) + \lambda_3\left(TREAT_{i,s} \times DI_i\right) + \lambda_4(WTO_t \times DI_i) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$

$$DI_i \begin{cases} = 1, \text{developing country} \\ = 0, \text{developed country} \end{cases}$$

Where λ_1 and λ_2 are the coefficients of interest. The interaction terms $TREAT_{i,s} \times WTO_t$ and $TREAT_{i,s} \times WTO_t \times DI_i$ respectively capture the impacts of the shock on CO2 emissions and the potentially varied responses between developed and developing countries.

3.2 Identification Strategy

As reported by Angrist & Pischke (2008), the parallel trend is one of the key assumptions behind the validity of the DDD strategy, which requires emissions for treated and control groups to follow a common trend in the pre-treatment period. The general approach to test the parallel trend is to display the pre-treatment trend to indicate that two groups have behaved in an alike pattern before the implementation of the treatment, which helps estimate the treatment effect more accurately because changes in results can be ascribed to the treatment. Figure 2 graphically report overall trends of various measures of CO2 emissions between the treated and the control groups before and after the treatment. Variations in both production and consumption emissions present a similar pattern in the pre-WTO period and vary in the post-WTO period. Furthermore, the treatment groups for developed and developing countries also should behave similarly before China's inclusion in the WTO under the DDD framework. Figure 3 depicts the evolutions of average production emissions and consumption emissions by income levels for the treatment group. The evolution of production emissions shows a corresponding trend in the pre-WTO period, whereas the consumption emissions sudden surge for developed countries one year before the treatment. However, it is challenging to

[6] Using data from International Monetary Fund (IFM) (2021), I distinguish developing countries and developed countries that are defined before 2001.

perform trends by comprising all potential controls in few graphs and unsuitable to verify the parallel trend assumption by simply showing the graph. Further validity test related to parallel trend would be operated in the robustness check section.

Figure2: Evolutions of Average CO2 Emissions by Group(kt)

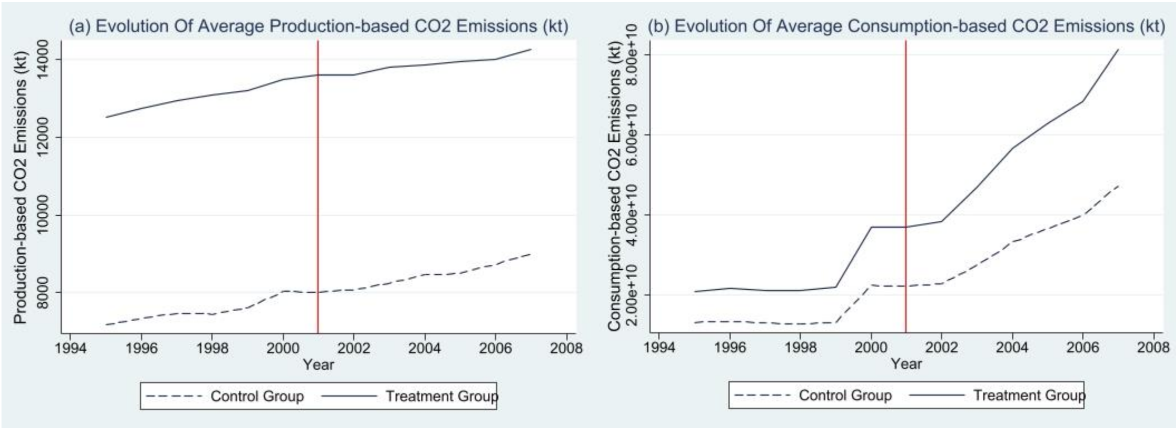
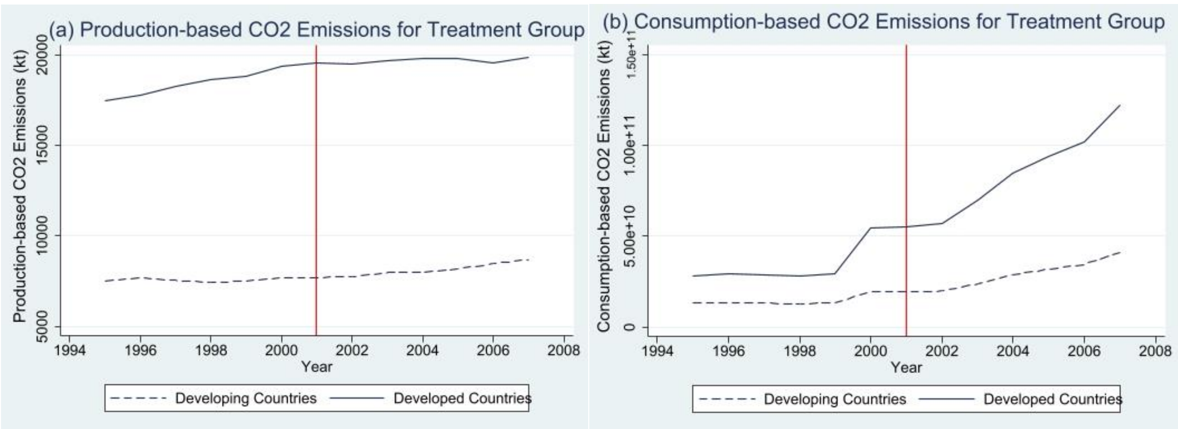


Figure3: Evolutions of Average CO2 Emissions by Income Levels for Treatment Group(kt)



4 Data

4.1 Data Source

To compute the impact of China's trade openness on the CO2 emissions of its related trading countries requires tracing the CO2 emissions embodied in trade between countries and across sectors. Additionally, intermediate goods should be included when calculating trade, and continuous data across countries and sectors over time are required to measure trade and emissions. The WIOD satisfies the above conditions and therefore, it becomes my prime source of data (Timmer et al., 2015). It consists of WIOT for the period from 1995 to 2011, covering 35 sectors across 40 countries, incorporating 27 countries of the European Union and the other 13 major countries in the world (Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Korea, Taiwan, Turkey, and the United States). This method would calculate CO2 emissions embodied in the plurality of global trades. As illustrated by Timmer et al. (2015) and Levitt (2019), these countries constitute around 85% of the world's GDP.

By combining bilateral international data and national input-output table, WIOT are gained. Based on ISIC rev. 2[7] classification, the WIOT data includes 35 sectors encompassing the economy for China and other 39 importing countries. The extent of sectors covers agriculture, construction, mining, utilities, 14 manufacturing industries and 17 service industries[8]. According to Timmer et al. (2015), each WIOT contains two components for each country—the intermediate output used in intermediate goods production by each sector and the final output used in final consumption by households, governments, and industries. I would measure these 35 sectors across 39 countries (exclude China) for 13 years from 1995 to 2007 to comprehensively analyse whether a Chinese trade openness event has disparate influences on CO2 emissions in different sectors and countries.

Furthermore, the WIOD also include the environmental satellite accounts, containing CO2 emissions for the identical range of sectors and countries of input-output tables, but measure a shorter period from 1995 to 2009 (Aurelien, 2012). The data on CO2 emissions from the environmental accounts were collected from the report of Guidelines for National Greenhouse Gas Inventories of International Panel on Climate Change (IPCC) in 2006 and report of United Nations Framework Convention on Climate Change (UNFCCC) emissions in 2011. I include these CO2 emissions data and combine them

[7] International Standard Industrial Classification of All Economic Activities reversion 2.

[8] The Appendix Table A1 list all 35 sectors.

with international trade to find the CO2 emissions embodied in the trade of each sector in each country.

In addition, to establish control variables for these accounts, I also include the socio-economic accounts from the WIOD. The socio-economic accounts complement input-output tables and utilise the identical sector and country classification from the WIOT, making it feasible to obtain data for the same 35 sectors in each country (Timmer et al., 2015). I incorporate total labour hours, the ratio of low-skilled workers, real gross output, and the ratio of gross fixed capital as the control variables in my regression model.

4.2 Variable

Table 1: Variables

Variable Name	Definition	Unit	Source
Independent Variable			
WTO_t (Event dummy)	Dummy variable: equals to 1 after China's accession into the WTO, and equals to 0 otherwise	/	WDI
$TREAT_{i,s}$ (Group dummy)	Dummy variable: equals to 1 when the observation is in the high exposure group, and equals to 0 otherwise	/	WIOT
DI_i (Status dummy)	Dummy variable: equals to 1 when the observation is a developing country, and equal to 0 otherwise	/	IFM
$TREAT_{i,s} \times WTO_t \times DI_i$	The triple-interaction term to capture potentially varied responses between developed and developing countries	/	/
$TREAT_{i,s} \times WTO_t$	The double-interaction term to capture the effect of the trade openness event on CO2 emissions	/	/
$TREAT_{i,s} \times DI_i$	The double-interaction term	/	/
$WTO_t \times DI_i$	The double-interaction term	/	/
Control Variable			
Gross Output	Gross output by industry at current basic prices	millions	WIOD
$\frac{\text{Gross Fixed Capital}}{\text{Real Gross Output}}$	The share of nominal gross fixed capital formation in gross output by industry at current basic prices	percentage	WIOD
Total Labour Hours	Total hours worked by persons engaged	millions	WIOD
$\frac{\text{Total Labour Hours of Low} - \text{skilled Labour}}{\text{Total Labour Hours}}$	The share of hours worked by low-skilled persons engaged in total hours worked by persons engaged	percentage	WIOD
Dependent Variable			
Ln Production-based CO2 Emissions ($CO2^P_{i,s,t}$)	Production-based CO2 emissions, which collected from WIOD	Gg (kt)	WIOD
Ln Consumption-based CO2 Emissions ($CO2^C_{i,s,t}$)	Consumption-based CO2 emissions, which covers all CO2 leaked from the goods and services production consumed by domestic	Gg (kt)	WIOD

4.2.1 Primary Independent Variables and Control Variables

In this paper, three dummies are included to construct the primary independent variables. The first is WTO_t, activating in 2002, one month after the time point that China became a member of the WTO (11 December 2001). The second one is a group dummy $TREAT_{i,s}$, separating the treated and untreated observations by identifying their trade exposure degrees. As I mentioned in the previous methodology, observations with low exposure to Chinese trade are classified as the control group, and the others with high exposure comprise the treatment group. Another key independent variable DI_i is added in this research to record potential inconsistent responses between developed and developing countries in the post-WTO period. By interacting with the above three indicator variables, $TREAT_{i,s} \times WTO_t$ and $TREAT_{i,s} \times WTO_t \times DI_I$ are generated to estimate the causal effect in the DDD framework.

Table 1 presents four control variables that control for the specific sector-time and country-time attributes in this paper, which mitigates the impact of confounding factors and increases the internal validity. Specifically, the gross fixed capital and low-skilled labour ratios are computed by dividing by real gross output and total labour hours using gross fixed capital and total labour hours of low-skilled workers, respectively.

4.2.2 Dependent Variable—CO2 Emissions

I calculate the aggregate emissions using a production-based method and a consumption-based method since they are the most general methods in many research to account for CO2 emissions embodied in the trade (Wiedmann et al., 2007; Wiedmann, 2009; Dong et al., 2010; Guo et al., 2012; Levitt, 2015; Levitt, 2019), which could provide a complete view to catch any variations in the structure of CO2 emissions.

The production-based method incorporates the CO2 emissions from the production of goods and services regardless of the place of consuming these products and services (domestic consumption or export). This approach is relatively straightforward because it is based on territory-related production, which only computes emissions arising within sovereign borders. The production emissions are directly obtained from the data in the WIOD’s environmental satellite accounts. However, this approach cannot reflect the production chains beyond the borders, ignoring the emissions from imported goods used for domestic country’s intermediate inputs or final consumption and the emissions from final goods export abroad.

To solve the above problems in production-based accounting, I measure emissions by applying a consumption-based measure. These emissions quantify CO2 emissions from the production of goods and services more detailedly since it reflects emissions embodied in the trade. Specifically, it adds emissions from a foreign country's import products (used for final domestic consumption or final domestic production) and subtracts emissions from domestic export products. This approach is based on territory-related consumption and estimates emissions occurring within and beyond sovereign borders. The advantage of this measure lies in its traceability of the origins of emissions embodied in final consumption. The discrepancy between production and consumption emissions is usually owing to the emissions emitted from international trade.

As the consumption-based CO2 emissions assess all the emissions from goods and services production consumed by domestic, it requires tracking the emissions associated with the whole process of goods' consumption. For instance, estimating the emissions related to consumption of good A involved tracing every production stage to manufacture A, including the emissions related to intermediate input B used to manufacture A. Moreover, to compute the emission of intermediate good B possibly involves accounting for other intermediate input C utilised to manufacture B from disparate sectors across different countries. Thus, the chain of emissions requires to account for the global chain of production.

I determine the consumption-based emissions by employing a multi-regional IO model applied by plenty of scholars (Wiedmann et al., 2007; Wiedmann, 2009, Guo et al., 2012; Levitt et al., 2015). I start to build the following matrix equation to calculate goods and services' flow across all sectors and countries:

$$\begin{vmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \end{vmatrix} = \begin{vmatrix} A_{1,1} & A_{1,2} & \cdots & A_{1,40} \\ A_{2,1} & A_{2,2} & & A_{2,40} \\ \vdots & & \ddots & \vdots \\ A_{40,1} & A_{40,2} & \cdots & A_{40,40} \end{vmatrix} \begin{vmatrix} X_1 \\ X_2 \\ \vdots \\ X_i \end{vmatrix} + \begin{vmatrix} \sum_{k=1}^{40} Y_{1,k} \\ \sum_{k=1}^{40} Y_{2,k} \\ \vdots \\ \sum_{k=1}^{40} Y_{40,k} \end{vmatrix}$$

Where i represents the 40 countries, j represents the countries who consume products, k represents the countries who produce products. Matrix X_i is a 35×1 vector represents the gross output for 35 sectors across 40 countries, which is comprised by the aggregate amount of intermediate goods consumption $A_{j,k} \times X_i$ and final goods consumption $Y_{j,k}$. Matrix $A_{j,k}$ is a 35×35 matrix, which shows the normalised input from country k on country j for one unit output of country j. Matrix $Y_{j,k}$ is a 35×1 column vector, indicating the output for each sector consumed by another country k but manufactured in the given country j. This equation can be transformed as the following expression:

$$X = (I - A)^{-1}Y$$

Where I indexes a 35×35 identify matrix, $\left(I - A_{j,k}\right)^{-1}$ is known as 'Leontief's inverse matrix'.

To generate the consumption-based CO2 emissions, I assigned emissions for 35 sectors across 40 countries, which is also the data for production-based emissions. The matrix e is expressed as follows:

$$e = \begin{vmatrix} e_1 & e_2 & \cdots & e_{40} \\ e_1 & e_2 & \cdots & e_{40} \\ \vdots & \vdots & \ddots & \vdots \\ e_1 & e_2 & \cdots & e_{40} \end{vmatrix}$$

Where e_i is a 35×35 diagonal matrix for each sector across 40 countries.

Thus, consumption-based emission $CO2_{i,s,t}^{C}$ for each country i's sector s in year t could be computed by multiplying the above matrix X and matrix e, and the estimated equation is as follows:

$$CO2_{i,s,t}^{C} = e \times (I - A)^{-1}Y$$

Finally, I would calculate $CO2_{i,s,t}^{C}$ for 35 sectors across 40 countries over 13 years.[9] All emissions are transformed to natural logarithms to assess the marginal changes in the dependent variables more intuitively.

4.3 Summary Statistics

Table 2 provides the summary statistics of the dataset utilised in the study, covering all available data from WIOD for 35 sectors in 39 countries (exclude China) within 13 years. Among these statistics, Ln consumption-based CO2 emissions with a mean of 22.75 are relatively higher than Ln production-based emissions since they account for all potential emissions associated with domestic consumption. From the statistics of dummy variables, 32.3% of the observations are in the post-treatment period, 49.2% are in the treated group, and 44.9% are in developing countries.

[9] Notably, I only collect the production and consumption emissions for 39 countries to construct my regression as the CO2 emissions of China would be excluded after finishing the matrix calculation.

Table 2: Summary Statistics

Variable (unit)	Mean	Std. Dev.	Min	Max	N
Ln Production-based CO2 Emissions (kt)	6.659	2.404	0.03	14.513	6113
Ln Consumption-based CO2 Emissions (kt)	22.75	1.508	20.222	26.812	6113
$\mathrm{WTO_t}$ (Event dummy)	0.323	0.468	0	1	6113
$TREAT_{\mathrm{i,s}}$ (Group dummy)	0.492	0.499	0	1	6113
$\mathrm{DI_i}$ (Status dummy)	0.449	0.497	0	1	6113
$TREAT_{\mathrm{i,s}} \times \mathrm{WTO_t} \times \mathrm{DI_i}$	0.084	0.278	0	1	6113
$TREAT_{\mathrm{i,s}} \times \mathrm{WTO_t}$	0.161	0.368	0	1	6113
$TREAT_{\mathrm{i,s}} \times \mathrm{DI_i}$	0.153	0.36	0	1	6113
$\mathrm{WTO_t} \times \mathrm{DI_i}$	0.245	0.43	0	1	6113
Gross Output (millions)	6880000	35500000	0	853000000	6108
Gross Fixed Capital Share (%)	11.59	111.727	0.013	150.993	6096
Total Labour Hours(millions)	1323.838	4472.211	0	79043.102	6108
Low-skilled Labour Share (%)	34.608	25.732	0.199	98	6108

5 Result

5.1 Exploratory Analysis

Figure 4: China's Imports and Exports, 1995-2007.

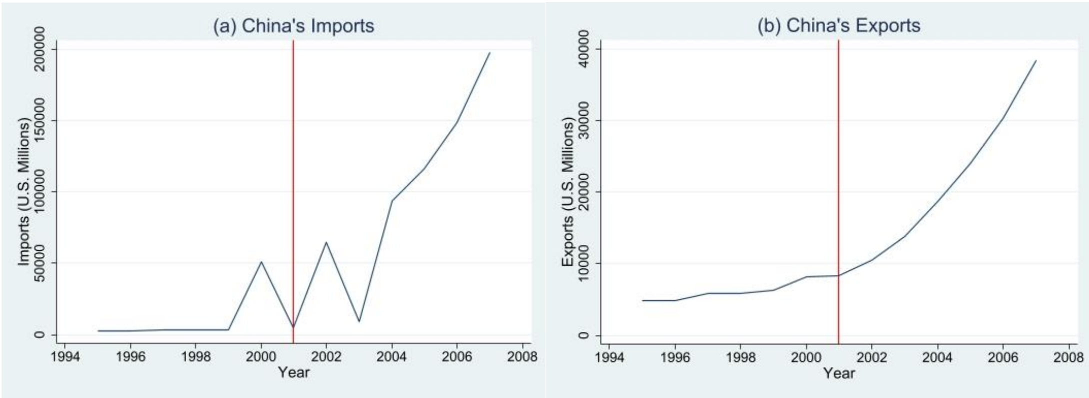
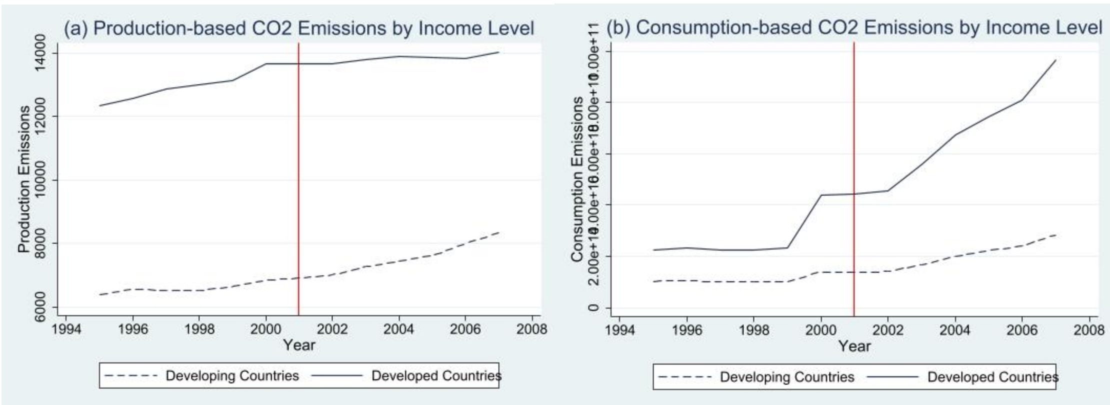


Figure 5: CO2 Emissions by Income Levels of Countries, 1995-2007.



Before stepping into the empirical model, some descriptive analyses need to show the alternations in international trade and CO2 emissions after China's admission into the WTO. Figure 4 reports China's imports and exports in panels 4(a) and 4(b), respectively. Chinese import trade has expanded since 1995 but with a shaper growth rate in imports after 2001, which is the time point for China to join the WTO. Specifically, Chinese import trade grew by more than 300% in the six years after this event. In the meantime, Chinese export trade also attained a high increase speed by at least 350% from 2001 to 2007.

Figure 5 presents the changes in CO2 emissions for all observations based on different measures by developing countries and developed countries. The production-based emissions are roughly unchanged for developed countries and inclined to rise for developing countries after 2001 (illustrated in panel 5(a)). In comparison, there was a substantial expansion in emissions calculated by consumption-based method especially for developed countries, which shows a substantial rise between 2001 and 2007. Notably, the volume of CO2 emissions for developed countries is much higher than emissions for developing countries in these two panels. This is not surprising as countries differ in terms of gross output and population size, contributing to the different emissions levels. Remarkably, 39 countries except China are incorporated in the dataset, in which the US is categorised into developed countries group with considerably high emissions relative to other countries.

From the exploratory analyses, the increases in Chinese import and export trade are consistent with the increase in CO2 emissions in the post-treatment period, providing suggestive evidence on the possible relationship between trade openness and its related emissions after China accedes to the WTO.

5.2 DDD Regression

Forming from equation 1, the DDD estimates the effects of the trade liberalisation event on production-based and consumption-based emissions, detailed in Table 3. Columns (1) and (4) encompass the basic specification. Columns (2) and (5) control countries and sectors' specific characteristics, and columns (3) and (6) additionally comprise fixed effects for country-sector and time trends. The left panel (a) of Table 3 reports results on production-based CO2 emissions, the right panel (b) on consumption-based CO2 emissions. From the left panel, the positive significant double-interaction term $TREAT_{i,s} \times WTO_t$ shows that within-sector total production-based CO2 emissions rise by around 8.3% for countries in sectors with high trade exposure than those with low exposure. Additionally, the triple-interaction term $TREAT_{i,s} \times WTO_t \times DI_i$ changes from positive to negative following a more complete model setup, which indicates the treatment has a more considerable effect in raising emissions for developed countries in contrast with developing countries. On the contrary, a 10.7% increment for developed countries in within-sector total emissions related to consumption after the shock (illustrated in the right panel). This 10.7% increase in consumption-based emissions is larger than the 8.3% increase in production-based emissions, implying that the impact on consumption emissions is more significant than production emissions. Again, when considering the negative triple-interaction coefficient at a 0.1% significance level, this event reduces the consumption emissions by 10% for developing countries compared to developed countries. Besides, results from the control variables also provide some references. For example, both two types of emissions rise with real gross output.

Table 3: DDD Regression on CO2 Emissions, Full Set

Model	(1)	(2)	(3)	(1)	(2)	(3)
	Panel (a) Ln Production-based CO2 Emissions			**Panel (b) Ln Consumption-based CO2 Emissions**		
$TREAT_{i,s} \times WTO_t \times DI_i$	0.637**	1.078***	-0.075*	-0.627***	-0.736***	-0.100***
	(0.221)	(0.212)	(0.031)	(0.134)	(0.135)	(0.013)
$TREAT_{i,s} \times WTO_t$	0.483***	0.452***	0.083***	1.330***	1.341***	0.107***
	(0.117)	(0.111)	(0.021)	(0.071)	(0.071)	(0.009)
$TREAT_{i,s} \times DI_i$	-0.262**	-0.192*	-3.479***	-0.282***	-0.279***	0.450***
	(0.086)	(0.082)	(0.164)	(0.052)	(0.052)	(0.068)
$WTO_t \times DI_i$	-0.928***	-1.368***	0.100***	-0.321***	-0.205**	-0.028**
	(0.123)	(0.121)	(0.023)	(0.075)	(0.077)	(0.009)
Gross Output		7.42e-09***	1.09e-09***		-2.28e-09***	2.83e-10***
		(9.12e-10)	(2.01e-10)		(5.79e-10)	(8.36e-11)
Gross Fixed Capital		0.009***	0		-0.001	-0.0005
		(0.003)	(0.001)		(0.002)	(0.0003)
Total Labour Hours		0.0001***	4.07-04***		-3.44e-05***	-2.56e-07
		(6.98e-06)	(7.01e-06)		(4.43e-06)	(2.92e-06)
Low-skilled Labour Share		-0.005***	-0.007***		0.003***	-0.003***
		(0.001)	(0.001)		(0.001)	(0.001)
Constant	6.733***	6.604***	8.898***	22.706***	22.658***	23.300***
	(0.039)	(0.064)	(0.152)	(0.024)	(0.041)	(0.063)
Control Variables	no	yes	yes	no	yes	yes
Country-sector Effect	no	no	yes	no	no	yes
Year Effect	no	no	yes	no	no	yes
R^2	0.014	0.097	0.990	0.068	0.087	0.996
Observations	6113	6096	6096	6113	6096	6096

Notes: The table provides a full set of DDD estimates of the impact of China's entry into the WTO on production-based emissions and consumption-based emissions. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where *p<0.05, **p<0.01 and ***p<0.001.

To further confirm the results, I narrow down the data by mainly focusing on 14 manufacturing sectors to further conduct the DDD estimation since the results of these two coefficients $TREAT_{i,s} \times WTO_t$ and $TREAT_{i,s} \times WTO_t \times DI_i$ are crucial for concluding this paper. Trades associated with manufacturing products usually have more dynamic responses to the treatment, which reveals emissions embedded in the trade more accurately (Levitt, 2019). Table 4 reports results for 14 manufacturing sectors. The double-interaction coefficient $TREAT_{i,s} \times WTO_t$ shows that the treated sectors experience growth in production emissions by 10.7% and consumption emissions by 13.3%. These results are all statistically significant at the 1% level, and the increment in production emissions is relatively lower than consumption emissions. Once again, the effects of this event on both production and consumption emissions for developing countries are smaller than developed countries when taking their negative significant triple-interaction coefficients into consideration. The above estimations are all consistent with results in Table 3 and further validate that China's entry into the WTO shows positive effects on consumption-based and production-based emissions.

Table 4: DDD Regression on CO2 Emissions, 14 Manufacture Sectors

Model	(1)	(2)	(3)	(1)	(2)	(3)
	Panel (a) **Ln Production-based CO2 Emissions**			**Panel (b)** **Ln Consumption-based CO2 Emissions**		
$TREAT_{i,s} \times WTO_t \times DI_i$	0.379	0.684*	-0.159**	-0.833***	-0.943***	-0.130***
	(0.353)	(0.342)	(0.051)	(0.215)	(0.213)	(0.02)
$TREAT_{i,s} \times WTO_t$	0.647***	0.630***	0.107**	1.371***	1.369***	0.133***
	(0.189)	(0.183)	(0.035)	(0.115)	(0.114)	(0.014)
$TREAT_{i,s} \times DI_i$	0.001	-0.082	1.726***	-0.218**	-0.213*	-0.368***
	(0.139)	(0.136)	(0.137)	(0.084)	(0.085)	(0.055)
$WTO_t \times DI_i$	-0.902***	-1.262***	0.165***	-0.201	-0.056	-0.019
	(0.192)	(0.189)	(0.036)	(0.117)	(0.118)	(0.014)
Gross Output		7.68e-09***	5.83e-10		-4.27e-09***	3.78e-0
		(1.74e-09)	(4.95e-10)		1.08e09	1.97e-10
Gross Fixed Capital		0.035***	-0.001		-0.011**	-0.002***
		(0.006)	(0.001)		(0.004)	(0.001)
Total Labour Hours		9.04e-05***	3.17e-05*		-2.33e-05**	-3.83e-06
		(1.32e-05)	(1.35e-05)		(8.24e-06)	(5.38e-06)
Low-skilled Labour Share		-0.007***	-0.011***		0.004***	-0.002*
		(0.002)	(0.002)		(0.001)	(0.001)
Constant	6.964***	6.884***	9.207***	22.697***	22.647***	23.283***
	(0.06)	(0.104)	(0.21)	(0.037)	(0.065)	(0.084)
Control Variables	no	yes	yes	no	yes	yes
Country-sector Effect	no	no	yes	no	no	yes
Year Effect	no	no	yes	no	no	yes
R^2	0.015	0.088	0.99	0.063	0.090	0.996
Observations	2496	2496	2496	2496	2496	2496

Notes: The table provides DDD estimates of the impact of China's entry into the WTO on production-based emissions and consumption-based emissions for 14 manufacturing sectors. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where *p<0.05, **p<0.01 and ***p<0.001.

5.3 Discussion of Results and Potential Mechanisms

From the above results, disparate increments in consumption and production emissions are observed succeeding the shock, and those increments differ between developed and developing countries. This section will discuss the results and explore possible channels through which China's entry into the WTO has affected CO2 emissions.

Table 5: Estimations of DDD on Production Emissions Intensity and Consumption Emissions Intensity

Variable	Ln Production Emission Intensity	Ln Consumption Emission Intensity
$TREAT_{i,s} \times WTO_t \times D_i$	-0.067	-0.072*
	(0.047)	(0.033)
$TREAT_{i,s} \times WTO_t$	0.085**	0.060**
	(0.032)	(0.022)
Control Variables	yes	yes
Country Effect	yes	yes
Sector Effect	Yes	Yes
Year Effect	Yes	Yes
R^2	0.963	0.990
Observations	6079	6092

Note: This table reports the estimation results of DDD regressions that assess the impact of China's entry into the WTO on production emission intensity and consumption emission intensity, respectively. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where *p<0.1, **p<0.05 and ***p<0.01.

Looking at columns (1) and (2) in Table 5, which depicts the within-sector effects of the event on the production and consumption emission intensities[10], countries' production and consumption emission intensities in high exposure sectors respective grow by 8.5% and 6% after China's accession into the WTO. It indicates that the expansions in two types of emission intensities associated with China originating from China's participation in the WTO result in changes in emissions. On the one hand, the production emissions emitted from the production of final products used for domestic and exports increase due to the expansion in its emission intensity. This outcome is consistent with Ozturk & Acaravci (2013) and Ren et al. (2014). They observe that trade originating from developing countries

[10] The equation for production emission intensity is defined as follows:

$$EmissionIntensity^{P}_{i,s,t} = \frac{Production - based\ CO2\ Emissions}{total\ exports + domestic\ production\ that\ is\ used\ \ for\ domesticlly\ consumed}$$

By analogy, I get the equation for consumption emission intensity:

$$EmissionIntensity^{C}_{i,s,t} = \frac{Consumption - based\ CO2\ Emissions}{total\ imports + domestic\ production\ that\ is\ used\ \ for\ domesticlly\ consumed}$$

Both production and consumption emissions compute the results from 35 sectors in 39 countries for 1995-2007.

usually accompanies high production emission intensity and results in rises in CO2 emissions. On the other hand, goods imported from China that contain more emissions rise thus leads to the addition in consumption emission intensity and then the growth in consumption emissions. This result coheres with the findings in Stretesky & Lynch (2009) and Xu et al.'s (2020) research, in which they comment that exports from developing countries tend to reinforce CO2 emissions as they include more emission-intensity intermediate goods and final goods such as oil, gas, chemicals and petroleum and coal products, and thus results in consumption emission intensity growth. Remarkably, developed countries usually have more considerable production and consumption emissions growth than developing countries after China accedes to the WTO when considering the negative significant triple-interaction coefficient. It echoes the findings of Baek et al. (2009), in which they perceive trades related to China have a benign effect on emissions in developing countries but a harmful effect in developed countries.

Taking the above outcomes together, the effect of this trade opening event on increasing the consumption emissions is larger than the production emissions. The discrepancy between production and consumption emissions is possibly due to the increment of high emission-intensity intermediate products imported from China, which lowers production emissions. This estimate aligns with Xu et al.'s (2020) opinion, in which they point out that the industries comprise high CO2 emissions usually are the industries that produce intermediate goods in China. Though there is a divergence between production and consumption emissions growth, the double-interaction coefficients $TRAET_{i,s} \times WTO_t$ still show positive signs, indicating the positive growth for both of them after China joins the WTO. It can be explained that the reduction in the CO2 emissions embodied in exports (from foreign countries to China) is only partially and smaller than the growth in the CO2 emissions embodied in imports (from China to foreign countries). By including the smaller positive growth in production emissions, the positive growth in emissions embodied in imports, and excluding the negative growth in emissions embodied in exports, a larger positive increase in consumption emissions after this event is therefore generated.

6 Robustness Check

6.1 Validity Test for the DDD Regression

Table 6: Parallel Trend Assumption Test

Regressor	Ln Production-based CO2 Emissions	Ln Consumption-based CO2 Emissions
$TREAT_{i,s} \times WTO_t \times DI_i$	-0.017	-0.006
	(0.028)	(0.011)
$TREAT_{i,s} \times WTO_t$	0.006	0.011
	(0.012)	(0.007)
$TREAT_{i,s} \times DI_i$	37.414	2.198
	(30.513)	(16.362)
$WTO_t \times DI_i$	-0.008	-0.007
	(0.027)	(0.008)
Control Variables	Yes	Yes
Country Effect	Yes	Yes
Sector Effect	Yes	Yes
Year Effect	Yes	Yes
R^2	0.994	0.997
Observations	1700	1700

Note: This table reports the results from a parallel trend test. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where * p<0.05, ** p<0.01 and *** p<0.001.

As the parallel trend is crucial for the DDD, a more precise test is needed to validate the results. Using data before 2002, the equation to be evaluated is as follows:

Equation 2: $$CO2^{j}_{i,s,t} = \alpha_{i,s} + \gamma_t + \lambda_1\left(TREAT_{i,s} \times WTO_t\right) + \lambda_2\left(TREAT_{i,s} \times WTO_t \times DI_i\right) + \lambda_3\left(TREAT_{i,s} \times DI_i\right) + \lambda_4(WTO_t \times DI_i) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$$

Where symbols remain the same as in previous equation 1, with the only variation being the variable WTO_t. The WTO_t variable indicates dummies for 1995 to 2001 as the reference. Regarding to equation 2, the parallel trend assumption holds if λ_1 and λ_2 are insignificant since they are the coefficients of interest in my paper.

Table 6 reports the outcomes from the parallel trend test in the above equation. The evaluated coefficients λ_1 and λ_2 in the pre-treatment period are statistically insignificant for production and consumption emissions, showing the null hypothesis of common trend cannot be rejected at a 0.1%

significance level. The triple-interaction term $TREAT_{i,s} \times WTO_t \times DI_i$ is close to zero and insignificant in both cases. Thus, this paper adopts the DDD as the key estimation strategy.

6.2 Estimation disregarding year fixed effects

Table 7: Estimation Disregarding Year fixed effects

Variable	Ln Production-based CO2 Emissions	Ln Consumption-based CO2 Emissions
$TREAT_{i,s} \times WTO_t \times D_i$	-0.033	-0.322***
	(0.028)	(0.019)
$TRAET_{i,s} \times WTO_t$	0.042*	0.354***
	(0.016)	(0.011)
$TREAT_{i,s} \times DI_i$	-3.429***	-0.095
	(0.162)	(0.110)
$WTO_t \times DI_i$	0.057**	0.216***
	(0.018)	(0.012)
Control Variables	yes	yes
Country Effect	yes	yes
Sector Effect	Yes	Yes
Year Effect	no	no
R^2	0.990	0.989
Observations	6096	6096

Note: This table reports the estimation results of the DDD without year fixed effects. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where * p<0.05, ** p<0.01 and *** p<0.001.

A possible issue with the current DDD equation would arise when considering the baseline results in Table 3. In this case, the triple-interaction coefficients change from positive to negative with lowering significance level after adding year and country-sector fixed effect. This outcome makes me doubt whether there is a larger impact of this trade openness event on increasing production and consumption emissions for developed countries than developing countries because the estimated coefficient could be exaggerate owing to time effects. The dependent variable and the treatment variable possibly share a common time trend as the dummy variable WTO_t switches no more than once at each sector in one country. To address this concern, I disregard time-series information and estimate the pre-treatment and post-treatment averages of the treatment effect using the approach Bertrand et al. (2004) proposed. The estimated coefficients should be still significant, and the sign of these coefficients is unchanged after ignoring the year fixed effect if the common trend does not overstate the treatment effect. Below is the model specification:

Equation 3: $CO2^{j}_{i,s,t} = \alpha_{i,s} + \lambda_1(TREAT_{i,s} \times WTO_t) + \lambda_2(TREAT_{i,s} \times WTO_t \times DI_i) + \lambda_3(TREAT_{i,s} \times DI_i) + \lambda_4(WTO_t \times DI_i) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$

Where the time fixed effect γ_t is deleted in contrast to equation 1. The other factors are the same as the definitions in the previous methodology.

Table 7 displays estimation results of the above specification after disregarding year fixed effects. The estimated double-interaction coefficients $TREAT_{i,s} \times WTO_t$ are still positive and significant. China's entry to the WTO results in a 4.2% growth in production emissions and a 35.4% increment in consumption emissions. Though the estimated coefficient for production emissions is not significant at a 5% level, the signs of triple-interaction coefficients are unvaried. Again, the outcomes align with the main results in Tables 3 and 4 that sectors in the treated group have experienced an increase in production and consumption emissions after China joined the WTO, and the effect is more considerable for developed countries. Notably, the time trend may play a role in explaining the impact of the treatment on the variations in production emissions between developed and developing countries considering the insignificant triple coefficient.

6.3 Test the event impact using a different estimator

Another DDD estimator is added to substantiate the choice of the treatment group, which utilises the temporary differential before and after China's participation in the WTO along with the differentials between the predetermined 2000 import trade exposure to China for domestic sectors across various countries in the whole sample. The specification can be estimated by the equation below:

Equation 4: $CO2^{j}_{i,s,t} = \alpha_{i,s} + \gamma_t + \lambda_1(IS^{China}_{i,s,2000} \times WTO_t) + \lambda_2(IS^{China}_{i,s,2000} \times WTO_t \times DI_i) + \lambda_3(IS^{China}_{i,s,2000} \times DI_i) + \lambda_4(WTO_t \times DI_i) + \sum \beta_i Z_{i,s,t} + u_{i,s,t}$

Where $IS_{i,s,2000}^{China}$ is the ratio of imports from China in the gross world import for sector s in country i[11]. The other factors follow the definitions in the preceding methodology. In the previous DDD setup, only the median import share is used as a benchmark to split up the treatment and control groups. Alternatively, 2000 import shares for all sectors across all available countries are adopted in this specification to explore complete changes before and after the treatment in the whole sample.

Table 8: Test the Event Impact Using a Different Estimator

Variable	Ln Production-based CO2 Emissions	Ln Consumption-based CO2 Emissions
$IS_{i,s,2000}^{China} \times WTO_t \times D_i$	-6.154**	-16.767***
	(2.199)	(1.594)
$IS_{i,s,2000}^{China} \times WTO_t$	-6.035***	13.879***
	(1.23)	(0.892)
$IS_{i,s,2000}^{China} \times D_i$	-1521.482***	-74.012
	(69.778)	(50.577)
$WTO_t \times D_i$	0.103***	0.241***
	(0.014)	(0.011))
Gross Output	1.49e-09***	7.31e-10***
	(2.03e-10)	(1.47e-10)
Gross Fixed Capital	0.0003	0.002**
	0.001	0.0005
Total Labour Hours	3.83e-05***	-2.74e-06
	(6.97e-06)	(5.05e-06)
Low-skilled Labour Share	-0.009***	-0.023***
	(0.001)	(0.001)
Control Variables	yes	yes
Country-sector Effect	yes	yes
Year Effect	yes	yes
R^2	0.99	0.987
Observations	6096	6096

Note: This table reports the results from DDD regression using a different estimator. Controls variables include total labour hours, the share of total labour hours of low-skilled workers, real gross output, and the share of gross fixed capital. Standard errors are in parentheses, where * p<0.05, ** p<0.01 and *** p<0.001.

Table 8 presents the results of CO2 emissions established from two different approaches for this equation. The signs of estimated coefficients in regression are almost consistent with the results reports in Tables 3 and 4 except for the double-interaction coefficient $IS_{i,s,2000}^{China} \times WTO_t$ of the

[11]Import share $IS_{i,s,2000}^{China}$ is defined in section 3, and all import shares for 39 countries (exclude China) and 35 sectors in 2000 are used in this regression.

production emissions. The consumption-based emissions are still impacted positively by China's accession to the WTO, while on the contrary, it appears to reduce the production emissions in this case. Once again, both types of emissions have more influence in developed countries than in developing countries.

7 Conclusion

This research investigates the impact of China's entry into the WTO on production CO2 emissions and consumption CO2 emissions under the DDD framework. From the empirical results, this trade openness event significantly positively impacts production and consumption CO2 emissions for both developed and developing countries. The impact of this event is larger on developed countries in contrast with developing countries. The possible reason behind these outcomes is that high emission-intensity final goods and intermediate goods increase through growth in imports after China accedes to the WTO. It thus leads to growth in the emission intensities for domestic production and consumption, which positively links with production and consumption emissions. Specifically, the growth in consumption emissions is higher than production emissions in the post-event period when comparing their magnitudes. This is because the additions in high emission-intensity intermediate goods imported from China reduce the emissions from the production of final goods for domestic and export, which partially diminishes production emissions.

This paper contributes to the existing literature on the association between trade policy and global environmental outcomes as well as trade openness, environmental effects, and country's income level. Additionally, it provides some evidence on the changes in CO2 emissions embodied in the international trade by conducting an IO analysis. While this paper attempts to catch variations in production and consumption emissions for both developed and developing countries after the treatment among sectors in different countries, several limitations exist and give potential improvement directions for future investigations. Due to the inconsistent coefficient of the impact of this event on production emissions in one of my robustness checks, this event's influence on production emissions needs to be further evaluated. From another robustness check, the triple-interaction term of production emissions appears insignificant after removing time fixed effects, which indicates that the variations in production emissions between developed and developing countries need an additional check. With the goal of further comprehending the effectiveness of China's entering the WTO on CO2 emissions, further studies can examine these impacts on another dataset.

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9 Appendices

Table A1. Industry Sector Division

ISIC Rev.2 Code	Sector
secAtB	Agriculture, Hunting, Forestry and Fishing
secC	Mining and Quarrying
sec15t16	Food, Beverages and Tobacco
sec17t18	Textiles and Textile Products
sec19	Leather, Leather and Footwear
sec20	Wood and Products of Wood and Cork
sec21t22	Pulp, Paper, Paper, Printing and Publishing
sec23	Coke, Refined Petroleum and Nuclear Fuel
sec24	Chemicals and Chemical Products
sec25	Rubber and Plastics
sec26	Other Non-Metallic Mineral
sec27t28	Basic Metals and Fabricated Metal
sec29	Machinery, Nec
sec30t33	Electrical and Optical Equipment
sec34t35	Transport Equipment
sec36t37	Manufacturing, Nec; Recycling
secE	Electricity, Gas and Water Supply
secF	Construction
sec50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
sec51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
sec52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
secH	Hotels and Restaurants
sec60	Inland Transport
sec61	Water Transport
sec62	Air Transport
sec63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
sec64	Post and Telecommunications
secJ	Financial Intermediation
sec70	Real Estate Activities
sec71t74	Renting of M&Eq and Other Business Activities
secL	Public Admin and Defence; Compulsory Social Security
secM	Education
secN	Health and Social Work
secO	Other Community, Social and Personal Services
secP	Private Households with Employed Persons